International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 1, Feb 2018, 133-144

EVALUATION OF EFFECT OF SHAPE AND LENGTH OF SPIKE ON AERODYNAMICS PERFORMANCE OF SUPERSONIC AXI-SYMMETRIC BODIES

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ABSTRACT

In this paper, the study of the aerodynamic performance of the aircraft which operates in both Hypersonic and Supersonic Flows has been carried out. The aerodynamics of the objects in these two regimes varies and is different in each. There is necessity for understanding the flow characteristics and applying it to a design which should be efficient in both the regimes.

In this project, we are going to analyze the effect of the Spike length and the shape of the spike on performance characteristics of body. For this, a reference model of a blunt nose is taken and Computational studies have been made to obtain the effect of a spike with a sharp tip and blunt tip on the flow over a hemi-spherically blunt body at different Mach numbers. Effect of spike length has been obtained and it is observed that increase in spike length reduces drag at supersonic speeds and the drag reduction due to shape is based on the Mach number and the shape of the spike. The project suggests that an adjustable spike system at the nose of the aircraft can improve the aerodynamic performance at small weight compensation.

KEYWORDS: Hypersonic Flows, Supersonic Flows, Spike Shape & Spike Length

Received: Nov 16, 2017; **Accepted**: Dec 06, 2017; **Published**: Dec 29, 2017; **Paper Id**.: IJMPERDFEB201816

Original Article

1 INTRODUCTION

Spike

A thin cylindrical rod generally placed at the extreme end of a small conical body is called as *Spike*; it is mounted at the nose on the supersonic aircraft. Shown in Figure 1

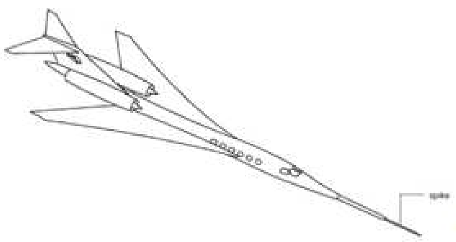


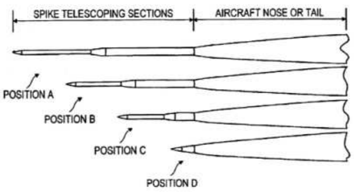
Figure 1: Aircraft with Spike

Spikes have been useful in reducing the aerodynamic drags around the blunt bodies like missiles, rockets etc. Spike is mainly useful as it converts the bow shock in front of above mentioned bodies into oblique shock. Spike flow field is characterized by spike shock reattachment shock, recirculation zone, shear layer etc. Studies on

spike at Supersonic regime have shown that use of spike has been effective in drag reduction. The vehicles like space plane, reusable launch vehicles, missiles, interplanetary space mission, and supersonic aircrafts usually employ spike over the nose blunt bodies, which are passing through the supersonic and hypersonic speed.

1.1: Types of Spike

The spike can be classified into two types; they are, fixed Spike and Variable Spike. Fixed spike as shown in figure 2(a)are rigid and their length cannot be varied where as the variable spikes is also known as 'Telescopic Spike' include several sections of varying cross-sectional area. The foremost, or farthest upstream, section of the spike preferably has a cross-sectional area which is characteristically small compared to that of the aircraft's full fuselage or fuselage fore body. Generally, subsequent (farther aft), downstream sections of the spike progressively increase in cross-sectional area. The variable spike is shown in Figure 2 (b).



(a)Fixed Spike **(b) Telescopic Spike**

Figure 2: Types of Spikes

However, a particular downstream section could have a smaller cross-sectional area than one or more upstream sections. The transitions between sections preferably occur through curved or generally conical transition surfaces. In preferred embodiments, the spike can be retracted into the fuselage when sonic boom mitigation is not needed or desired. For example, it may be desirable to retract the spike into the fuselage when the aircraft is flying at subsonic speeds, flying at supersonic speeds-over areas where sonic boom mitigation is deemed unnecessary (such as over an ocean), or is on the ground (to facilitate taxiing and parking).

2. PROPOSED METHODOLOGY

As the aim of the project is to study the effect of spike shape and size on the performance of the aircraft cruising at supersonic speeds, the project intends to find the drag of the aircraft with different spike configurations. For this, a blunt body has been modeled to which these spikes of different shapes and lengths have been attached. These models are later analyzed in Fluent to predict their aerodynamic characteristics.

2.1 Problem Description

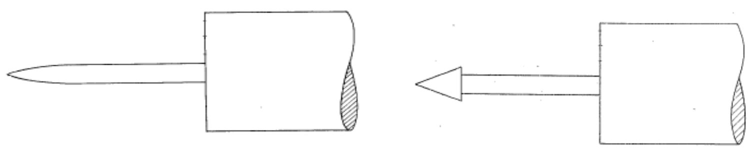
To study the effect of shape and length of the spikes, four different nose shapes and three different lengths have been considered. The length of the spike is taken as the function of the diameter of the body and is given by the ratio of the spike length and diameter of the body.

2.2 Shape of Spike

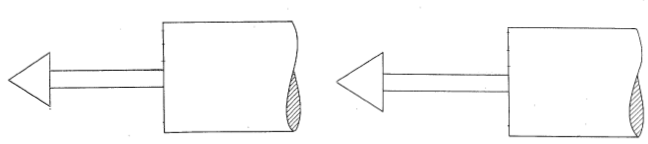
To study the effect of the shape four different nose shapes have been considered. They are:

- Ogival Shape
- Cone with semi angle of 15^0
- Cone with semi angle of 30^0
- Cone with semi angle of 40^0

The above mentioned shape of the Spike which are considered for the analysis are given in figures 3 (a), (b), (c) and (d) respectively.



(a) Ogival Shape **(b)Cone with semi angle 150**

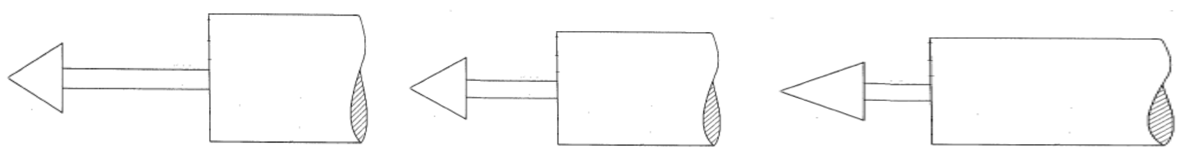


(c)Cone with Semi Angle 300 **(d) Cone with Semi Angle 400**

Figure 3: Shapes of Spikes

2.3: Length of Spike

To study the effect of length of the spike, different length to diameter ratios have been considered. The length of spike is taken with respect to the size of the aircraft nose. For this, length of spike (*l*) to diameter of nose ratio (d) has been considered as a parameter. As an initial values l/d is considered as 1and varied with an interval of 0.5 for three cases



(a) l/d =2 **(b) l/d = 1.5** **(c) l/d =1**

Figure 4: Shapes of Spikes

2.4 Summary of Models to be Analyzed in Fluent

The total number of cases that are going to be solved in the present work are tabulated and given in Table 1

Table 1: Cases to be Solved

S No	L/D	Case No	Shape of the Spike Nose
1.	**0**	1	**No Spike**
2.	1	2	Ogival with radius of 203.5 mm
3.		3	Cone with 15^0 semi angle
4.		4	Cone with 30^0 semi angle
5.		5	Cone with 40^0 semi angle
6.	1.5	6	Ogival with radius of 203.5 mm
7.		7	Cone with 15^0 semi angle
8.		8	Cone with 30^0 semi angle
9.		9	Cone with 40^0 semi angle
10.	2	10	Ogival with radius of 203.5 mm
11.		11	Cone with 15^0 semi angle
12.		12	Cone with 30^0 semi angle
13.		13	Cone with 40^0 semi angle

3. MODELING AND ANALYSIS

2D modelswere developed for each case and analyzed for the required conditions in Fluent

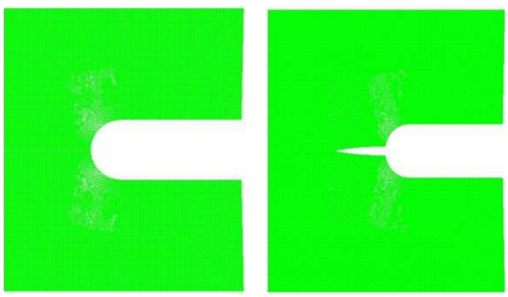
3.1 ANSYS Fluent

ANSYS Fluent is a state-of-the-art computer program for modeling fluid flow, heat transfer, and chemical reactions in complex geometries.

ANSYS Fluent provides complete flexibility, including the ability to solve your flow problems using unstructured meshes that can be generated about complex geometries with relative ease.

3.2 FLUENT Setup

Since the model is considered as Axisymmetric, A 2D model has been considered instead of completed 3D model. A 2D axisymmetric analysis was carried to evaluate the flow. With this approach, the computational effort has been reduced to some extent and a comparatively batter results have been achieved by eliminating the 3D Meshing Errors. The meshed generated for one the cased is given in figure 6(a) and Figure 6(b)



(a) Mesh for Body without spike **(b) Mesh for Body with spike**

Figure 6: 2D Meshing of Model

4. RESULTS AND DISCUSSIONS

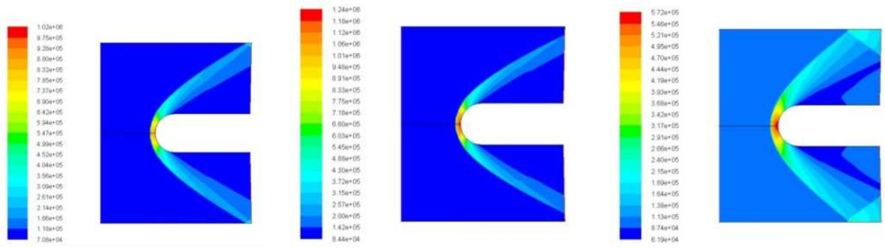
The present section deals with the study of the results obtained from the analysis and necessary output is discussed. The flow conditions are taken as Mach number varying between 2 to 3. Due to space constraint only Pressure

contours have been included in paper

For initial condition, the body without spike is taken and the various spike lengths have been tested with different shapes. The various cases are given table 1

4.1 Results

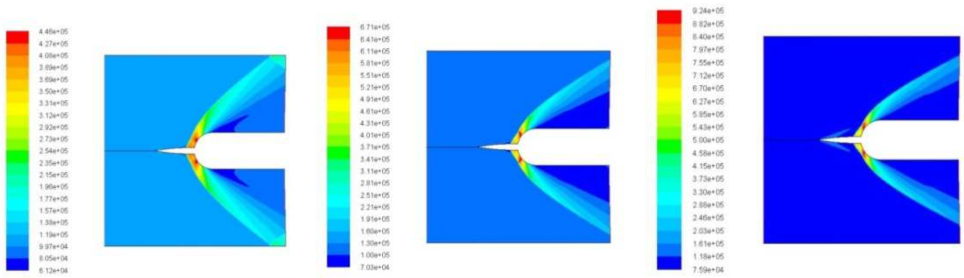
Case-1: The Pressure contours for the blunt body without Spikeat various Mach Numbers is generated and given in figure7 (a,b,c) below



(a) Contours for M=2 **(b) Contours for M=2 .5** **(c) Contours for M=3**

Figure 7: Pressure Contours for Blunt Body without Spike

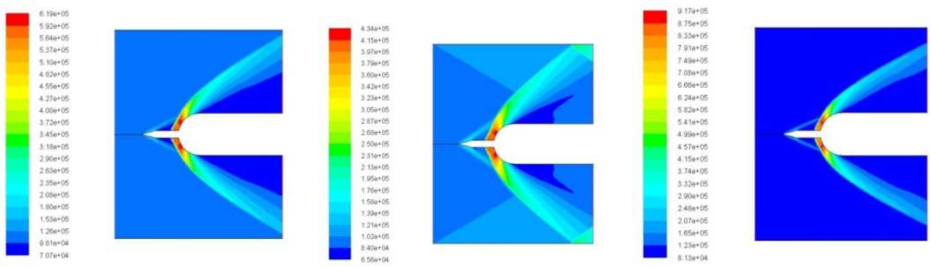
Case-2: The Pressure contour s for the blunt body with an Ogival shaped Spike of *l/d* =1 at various Mach Numbers is given in the figures 8 (a,b,c)



(a) Contours for M=2 **(b) Contours for M=2 .5** **(c) Contours for M=3**

Figure 8: Pressure Contours for Blunt Body with Ogival Spike of l/d=1

Case-3: The Pressure contour s for the blunt body with a conical Spike of angle 30^0 and *l/d* =1 at various Mach Numbers isgiven in the figures 9 (a,b,c)

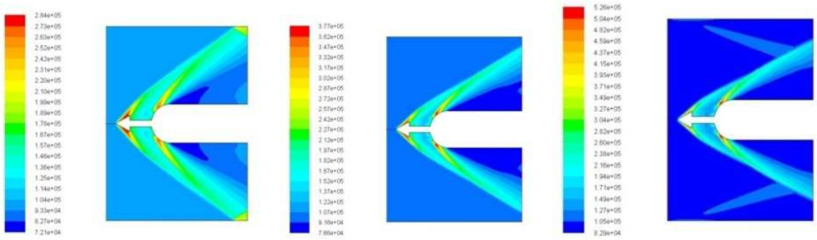


(a) Contours for M=2 **(b) Contours for M=2 .5** **(c) Contours for M=3**

Figure 9: Pressure Contours for Blunt Body with Conical Spike of Angle 300 and l/d =1

Case-4: The Pressure contour s for the blunt body with a conical Spike of angle 60^0 and *l/d* =1 at various Mach

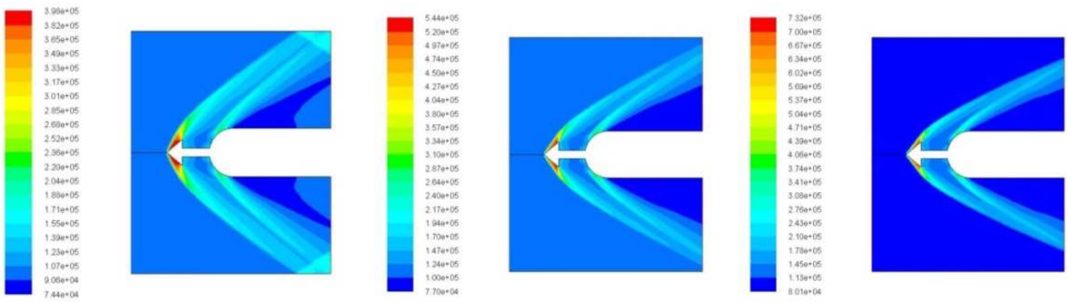
Numbers isgiven in the figures 10 (a, b, c)



(a) Contours for M (b) Contours for M=2 .5 (c) Contours for M=3

Figure 10: Pressure Contours for Blunt Body with Conical Spike of Angle 600 and l/d =1

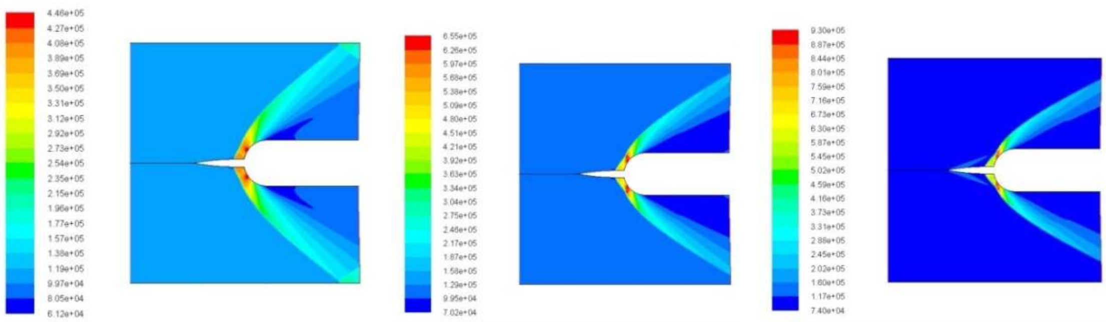
Case-5: Pressure contour s for the blunt body with a conical Spike of angle 80^0 and *l/d* =1 at various Mach Numbers is given in the figures 11(a, b, c)



(a) Contours for M=2 (b) Contours for M=2 .5 (c) Contours for M=3

Figure 11: Pressure Contours for Blunt Body with Conical Spike of Angle 800 and l/d =1

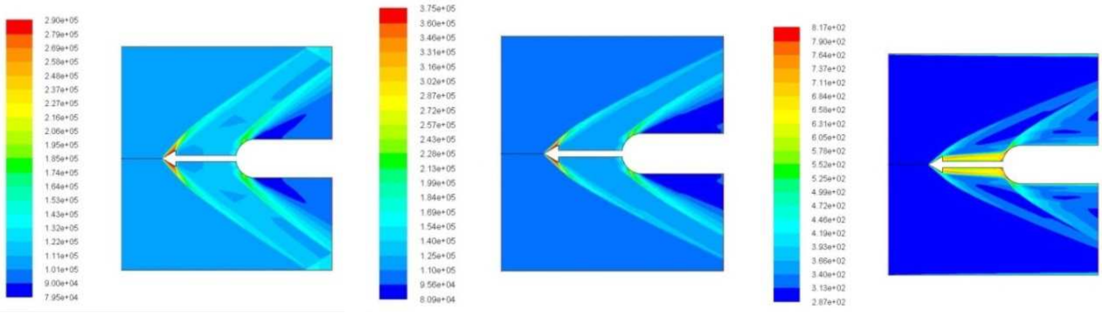
Case-6: The Pressure contour s for the blunt body with an Ogival shaped Spike of *l/d* =1.5 at various Mach Numbers is given in the figures 12 (a,b,c)



(a) Contours for M=2 (b) Contours for M=2 .5 (c) Contours for M=3

Figure 12: Pressure Contours for Blunt Body with Ogival Spike of l/d=1.5

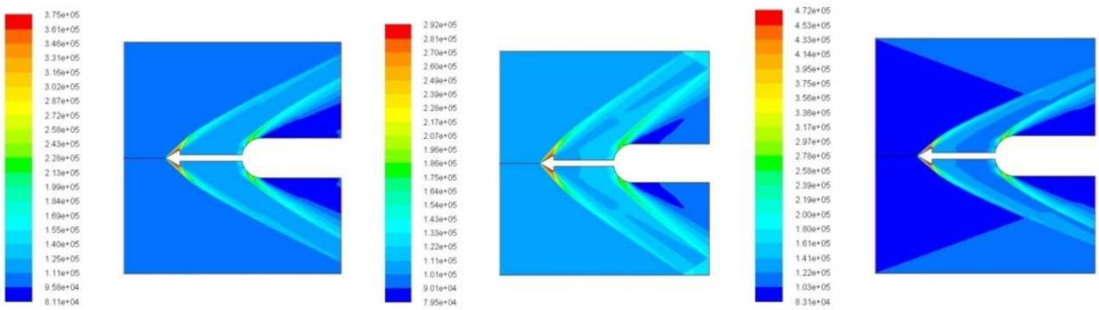
Case-7: The Pressure contour s for the blunt body with a conical Spike of angle 30^0 and *l/d* =1.5 at various Mach Numbers is given in the figures 13 (a, b, c)



(a) Contours for M=2 **(b) Contours for M=2 .5** **(c) Contours for M=3**

Figure 13: Pressure Contours for Blunt Body with Conical Spike of Angle 300 and l/d =1.5

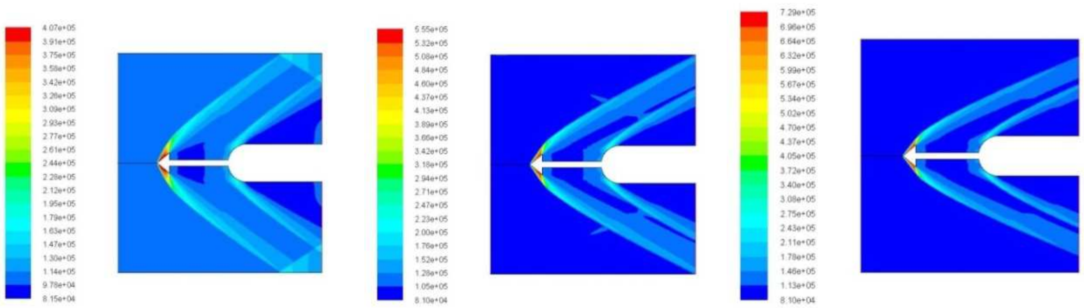
Case-8: The Pressure contour s for the blunt body with a conical Spike of angle 60^0 and *l/d* =1.5 at various Mach Numbers is given in the figures 14(a, b, c)



(a) Contours for M=2 **(b) Contours for M=2 .5** **(c) Contours for M=3**

Figure 14: Pressure Contours for Blunt Body with Conical Spike of Angle 600 and l/d =1.5

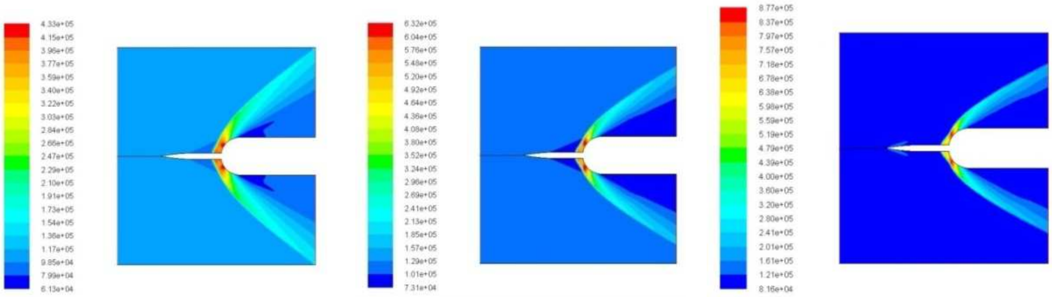
Case-9: The Pressure contour s for the blunt body with a conical Spike of angle 80^0 and l/d =1.5 at various Mach Numbers is given in the figures 15(a, b, c)



(a) Contours for M=2 **(b) Contours for M=2 .5** **(c) Contours for M=3**

Figure 15: Pressure Contours for Blunt Body with Conical Spike of Angle 800 and l/d =1.5

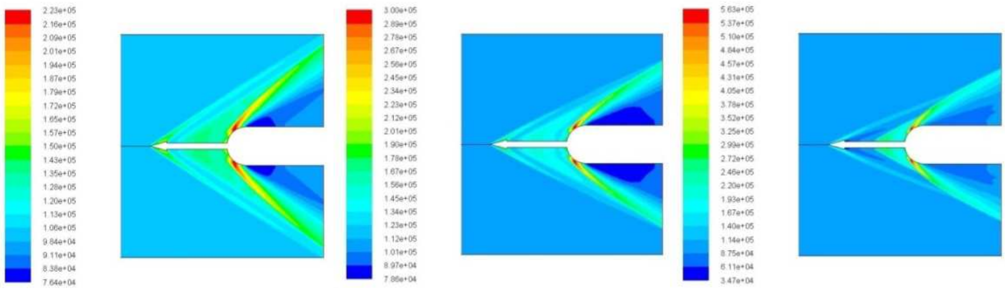
Case-10: The Pressure contour s for the blunt body with an Ogival shaped Spike of *l/d* =2 at various Mach Numbers is given in the figures 16 (a,b,c



(a) Contours for M=2 **(b) Contours for M=2 .5** **(c) Contours for M=3**

Figure 16: Pressure Contours for Blunt Body with Ogival shaped Spike of l/d =2

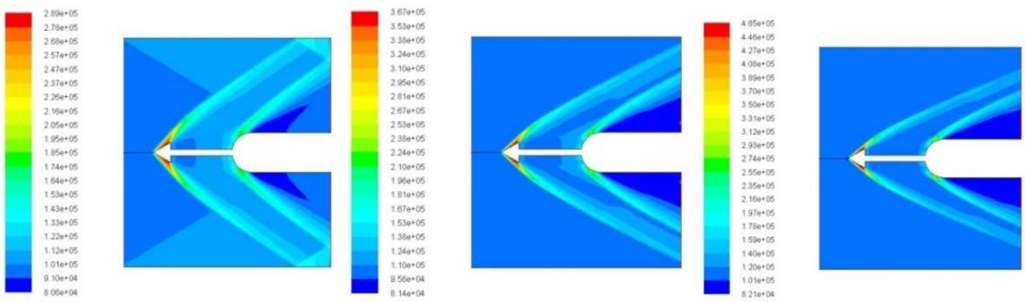
Case-11: Pressure contour s for the blunt body with a conical Spike of angle 30^0 and *l/d*= *2*at various Mach Numbers is given in the figures 17 (a,b,c)



(a) Contours for M=2 **(b) Contours for M=2 .5** **(c) Contours for M=3**

Figure17: Pressure Contours for Blunt Body with Conical Spike of Angle 300 and l/d =2

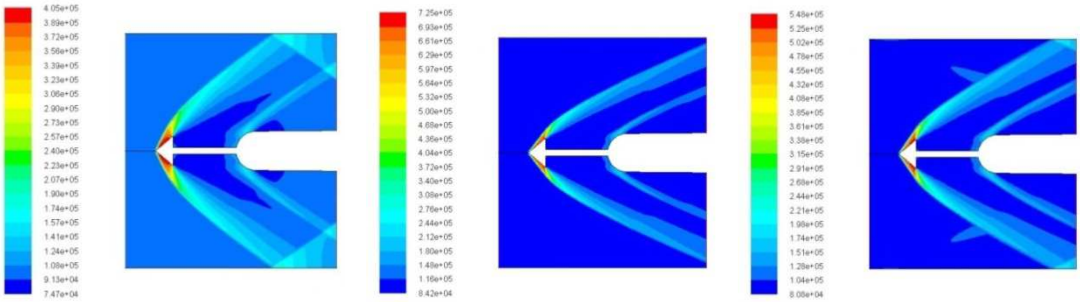
Case-12: Pressure contour s for the blunt body with a conical Spike of angle 600 and l/d= 2 at various Mach Numbers is given in the figures 18 (a,b,c)



(a) Contours for M=2 **(b) Contours for M=2 .5** **(c) Contours for M=3**

Figure 18: Pressure Contours for Blunt Body with Conical Spike of Angle 600 and l/d =2

Case-13: Pressure contour s for the blunt body with a conical Spike of angle 800 and l/d= 2 at various Mach Numbers is given in the figures 17 (a,b,c)



(a) Contours for M=2 **(b) Contours for M=2 .5** **(c) Contours for M=3**

Figure 19: Pressure Contours for Blunt Body with Conical Spike of Angle 800 and l/d =2

4.2 DISCUSSIONS

From the above results obtained, the following characteristics have been studied to predict the aerodynamic performance of the body due to addition of the spike to it.

4.2.1 Effect of Shape of Spike

Firstly, the effect of presence of spike in reduction of drag has been studied. This can be better understood based on the graph plotted between the drag of the body and the shape of the spike. This graph is plotted for different Mach numbers varying from 2 to 3.

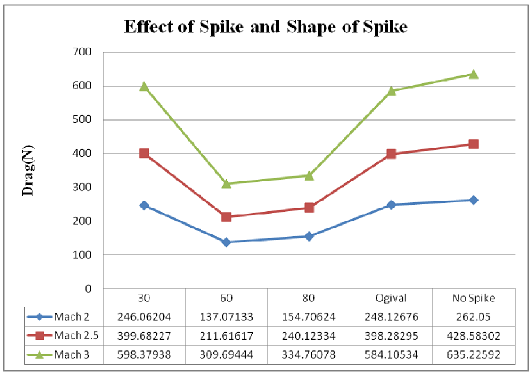
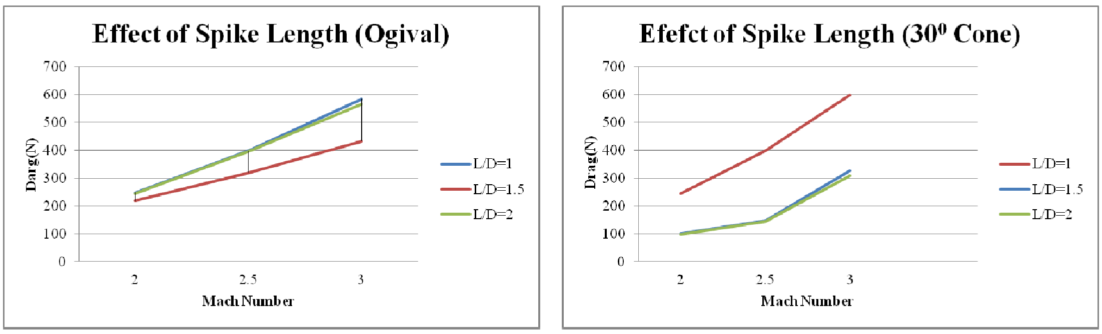


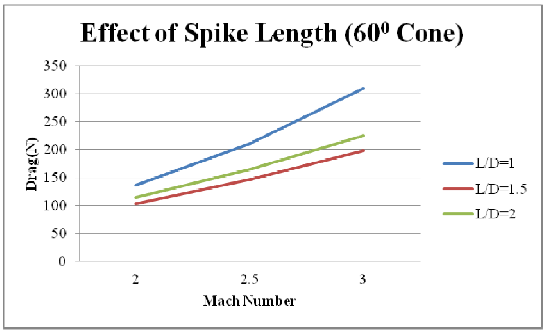
Figure 20: Graph to Study the Effect of Spike and Shape of Spike

4.2.21 Effect of Length of Spike

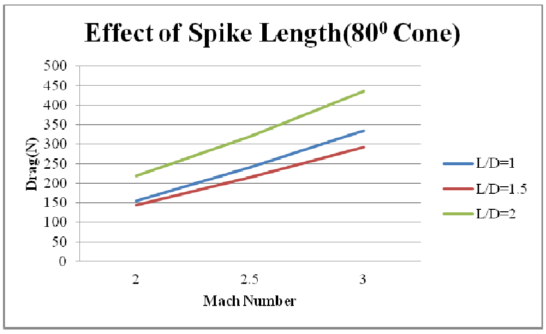
The effect of the length of spike can be understood by study of the following Graphs given in figure 21



(a) Effect of length for Ogival Shape **(b) Effect of length for 300Cone Shape**



(c) Effect of length for 600Cone Shape



(d) Effect of length for 800Cone Shape

Figure 21 Graphs to Study the Effect of Spike Length

6. CONCLUSIONS

From the graphs plotted in the previous chapter, following aspects can be pointed out.

By using spikes for the supersonic and Hypersonic Vehicles, the Pressure Drag can be reduced.The shape of the spike has great influence on the reduction of the drag of the body. This can be better explained by using the graph given in Figure 21. In this graph, the drag is more in case of the 30^0 cone spike (246) and the 80^0 cone spike (154) when compared to that of 60^0 cone spike (137). Thus, it is important to select appropriate shape for the supersonic vehicle for optimal performance at the given Mach number.The effect of the length of the spike can be explained using Figure 21. The figure consists of four plots between drag and the L/D ratio of the body at various Mach numbers. The graphs clearly indicate that, for Ogival and 30^0cone Spike the L/D=1.5 is yielding a good results in terms of the drag at the given Mach number where as for 60^0 cone and 80^0 Cone the L/D=2 is producing good results.Thus, while designing a supersonic Aircraft it is important to use spikes and if possible variable length spike.

7. FUTURE SCOPE

The project has enlightened on the requirement of the variable size and length of the spike while cruising at different mach numbers. Hence, as a future scope the team has decided to carry out the work on the design of the mechanism which can be employed on the aircrafts which would help in change the length and shape of the spike.

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